Flat Plate Vortex Shedding Noise Suppression with Surface Dielectric Barrier Discharge Plasma Actuators

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INTRODUCTION

Flow phenomena such as boundary layer separation and vortex shedding over bluff body can emit aerodynamic noise effectively. For a wind turbine operating in high loading configuration, the likelihood of flow separation not only negates the aerodynamic/structural stabilities, but also tends to result in significant noise radiation. Aerodynamic noise is also a major problem for civil aviation industry, where further reduction of noise level radiated from the fan engine and landing gear remains a necessary, but extremely challenging task. Because the aerodynamic noise source is closely linked to the boundary layer or wake of the flow body, noise reduction could be achieved by effective flow control.

During the last decades, Active Flow Control (AFC) has been receiving a lot of attention. This is because the AFC allows the users to switch on and off the system depending on the flow conditions, hence minimizing the parasite drag. A fully autonomous AFC that utilizes a feedback mechanism can also be developed to respond to variation in flows without continuous input from the users. Passive Flow Control (PFL), on the other hand, does not require external power and is easier to implement. However, the geometries associated with the PFL is usually fixed, thus they are not suitable if the flow conditions vary considerably. This paper investigates the use of AFC technique to reduce the narrowband vortex shedding tonal noise radiated from a flat plate with blunt trailing edge.

One of the promising AFC techniques to receive a considerable attention lately is the use of surface dielectric barrier discharge plasma actuators (DBD). In addition to the aforementioned benefits pertaining to the AFC, these DBD plasma actuators offer the following advantages: they are easy to apply, have no moving parts, have very high response time, and low power consumption.

DBD plasma actuators are normally composed of two electrodes. One of the electrodes is exposed to the air to which high voltage is supplied to from an AC high voltage power supply [1]. The other electrode, ground electrode, is usually covered by one or more layers of a dielectric material such as Kapton tape. When a high AC voltage (~ kV) is applied to the active electrode, an electric field is generated between the two electrodes. The generated electric field will ionize the air above the active electrode. Due to the collision between the generated ions and the neutral particles, the resulting electric body force will produce electric wind propagating as a surface jet parallel to the flow direction [2].

DBD plasma actuators have been investigated both experimentally and numerically for the flow separation control at high angles of attack [3], flow control using aggregate plasma synthetic jet [4] and turbulent drag reduction [5]. The DBD plasma technique has also been applied to suppress the bluff body broadband noise, where up to 3dB noise reduction has been demonstrated in the frequency range of interest [6].

For a flat plate with a blunt trailing edge, the resulting vortex shedding in the wake will produce a by-product where considerable level of narrowband tonal noise can be radiated into the far field. In the current study, a surface DBD plasma actuator is used to suppress the vortex shedding noise generated at a free stream velocity of 7.5 ms^{-1}. Two actuator configurations have been studied; the first configuration is expected to produce tangential wind (PA1), whilst another configuration is expected to produce downward wind (PA2).

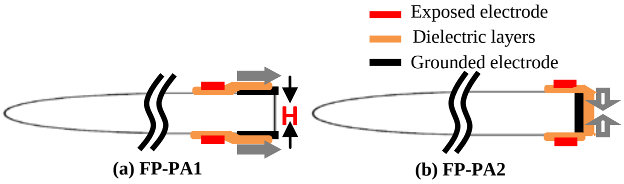

Figure1: Plasma actuator configurations (a) PA1, and (b) PA2.

PLASMA ACTUATOR AND EXPERIMENTAL INSTRUMENT

Two configurations of plasma actuators are investigated in the current study. The first is the tangential actuator (PA1) and the second is the downward actuator (PA2) as shown in Figure 1. Both the exposed and grounded electrodes are made of 0.035 mm thick copper tape. The widths for the PA1 and PA2 are 6 mm and 5 mm, respectively. The length of the electrodes is 280 mm covering the flat plate span-wise width. The ground electrode combines maximum of five layers of Kapton tape as a dielectric material. The total thickness of the dielectric is 0.24 mm. Both the PA1 and PA2 plasma actuators are installed near the blunt trailing edge as shown in Fig. 1. The flat plate is 150 mm in length, 300 mm in width and 6 mm in thickness (H). The leading edge of the flat plate is elliptical in shape to help preventing the boundary layer separation near the leading edge. The boundary layers on the upper and lower surface of the flat plate were tripped into turbulent using rough sandpaper. A high AC voltage supply (MiniPulse 6) is connected to the exposed electrode. The high voltage supply is capable of producing up to 60 kV peak-to-peaks, while an auxiliary port enables connection to a LeCroy Wave Station signal generator. The range of the output voltages that are investigated in the current study is from 3 to 7.2KV. In the present study, only the square wave signal is used to drive the voltage supply, which produces a sine wave as an output signal. The experiment was conducted in the aeroacoustic facility (anechoic chamber and open jet wind tunnel) at Brunel University London. Noise measurements were taken by a single 1/2″ free field pre-polarized condenser microphone (LarsonDavis 377B02). The microphone was situated at 1 m above the trailing edge of the flat plate at mid-span. Velocity measurements were also conducted downstream of the flat plate’s blunt trailing edge to investigate the wake flow. The near wake velocity profile was measured by a glass Pitot tube to avoid arching between the plasmas actuator and flow measuring probe of metal type. Hot wire probe was used at the far field wake to measure both the static and fluctuating velocities.

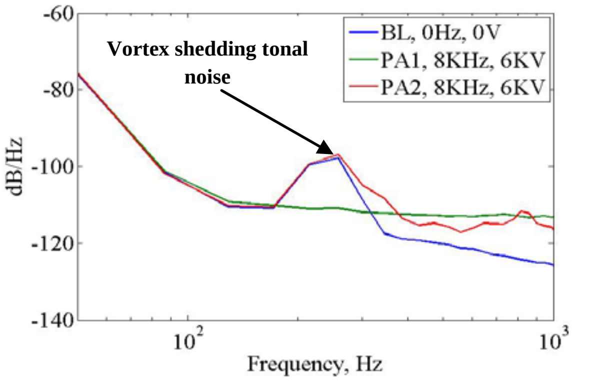

Figure 2: Comparison acoustic spectral produce by plasma configuration PA1 and PA2.

RESULTS

A comparison is made between plasma configurations PA1 and PA2 at different applied frequencies (6.5 to 9 kHz) and at maximum output voltage of (6 kV), which is just below the breakdown voltage of the actuators. Figure 2 shows the acoustic spectral (1 Hz bandwidth) pertaining to the baseline (plasma off), PA1 and PA2 cases. Note that the negative decibel of the sound pressure spectrum is because the sensitivity of the far filed microphone signal was not calibrated against the acoustic pressure. Nevertheless, the comparison among the different acoustic spectral is still valid. From the figure, a distinct tonal peak is observed at 257 Hz for the baseline case. The same narrowband frequency is also found in the wake velocity spectral density (see Fig. 4.b), which clearly attributes to the vortex shedding frequency. When the plasma actuators are turned on under configuration PA2, the narrowband vortex shedding tonal noise can be completely suppressed, resulting in 13 dB noise reduction. However, plasma configuration PA1 is less successful. One observation is that the plasma actuators generate considerable level of non-flow related self-noise at higher frequency. This important issue will be investigated in the future, but the focus on the current study is on the narrowband, vortex shedding tonal noise.

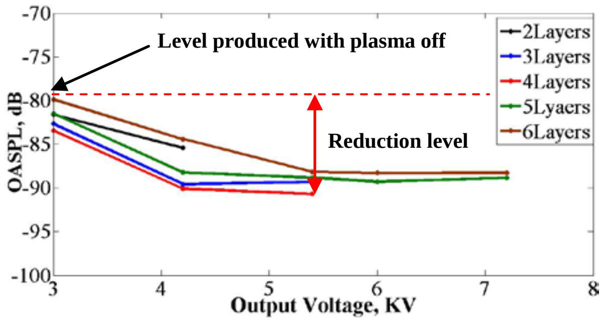

Figure 3: Effect of number of layers on the OASPL at different applied voltages under plasma PA2.

Further investigations are performed to determine the optimal thickness of the dielectric material, input voltage and frequency. The analysis method is to integrate the measured acoustic pressure from 130 Hz to 290 Hz to introduce the Overall Sound Pressure Level (OASPL) of finite frequency range. This particular frequency range corresponds to the lower limit and upper limit, respectively, for the narrowband vortex shedding noise as shown in Fig. 2. An example is shown in Fig. 3, which demonstrates that at an 8 kHz input frequency, the largest tonal noise reduction is achieved through the highest input voltages and 3-4 layers of dielectric in the PA2 plasma configuration. We should state that 5 layers of dielectric, though slightly less effective in tonal noise reduction, were adopted during the flow measurements because this configuration leads to longer actuation time compared with the four-layer case.

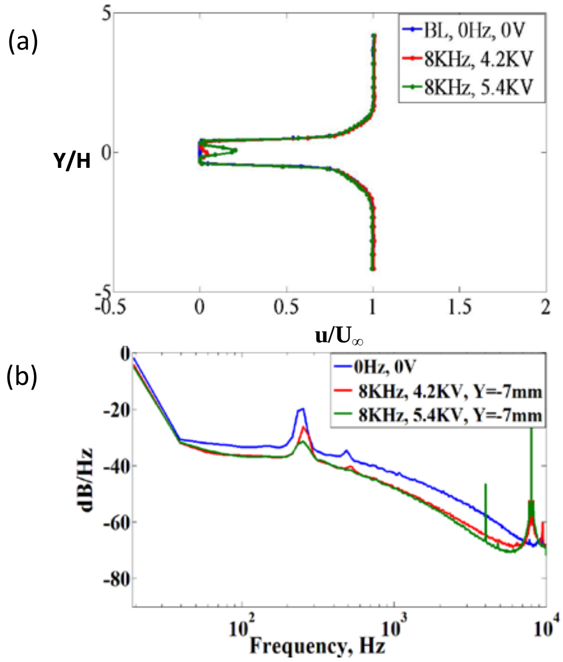

Figure 4: (a) Velocity profile at 1mm from the TE, (b) Velocity spectral densities at 25 mm downstream the TE and -7mm in the downward direction.

As shown in Fig. 4a, the measured velocity profile in the near wake region (1 mm downstream of the blunt trailing edge) exhibits a dead air pocket for the baseline (plasma off) case. When the plasma is driven at 5.4 kV and 8 kHz, an air jet of about 25% of the free stream velocity is induced by the ionic wind at the wake deficit region. This wake filling effect is expected to inhibit the vortex shedding formation, reducing both the base drag as well as the tonal noise simultaneously. At further downstream of 25 mm from the blunt trailing edge, and -7 mm vertically downward from the plate half-thickness, hot-wire data is converted to the velocity spectral density for both the plasma on/off cases. The results of the velocity spectral density demonstrate that, at 8 kHz and 5.4 kV, there is a reduction in the vortex shedding peak of about 10 dB compared with the baseline case. The velocity spectral densities at other frequencies are also lower than the baseline case when the plasma actuators are turned on, indicating the reduction in turbulence intensity in the wake.

OUTLOOK

The selection of results presented in this abstract demonstrates that the plasma actuator configuration PA2 can suppress the vortex shedding tonal noise significantly. Similar level of reduction in the velocity spectral density peak is also achieved, thus confirming the causal relationship of the velocity-noise fields. More comprehensive results in the noise and flow fields will be presented during the meeting.

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